(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 862 336 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
02.09.1998 Bulletin 1998/36

(51) Int Cl.6: H04N 9/73

(21) Application number: 98301419.2

(22) Date of filing: 26.02.1998

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 28.02.1997 US 808918

(71) Applicant: Hewlett-Packard Company
Palo Alto, California 94304 (US)

(72) Inventors:
- Winter, Kurt A.
Escondito, California 92026 (US)
- Sansom-Wai, Cindy V.
San Diego, California 92128 (US)
- Hubel, Paul H.
Mountain View, California 94040 (US)

(74) Representative: Molyneaux, Martyn William
Langner Parry
52-54 High Holborn
London WC1V 6RR (GB)

(54) Automatic white balance detection and correction of an image captured in a digital camera

(57) A method and apparatus for performing color balance enhancement using either a host or a device internal to the camera to adjust the color of a digital image taken by a digital camera. Digital image data representing the image is analyzed to determine the amount of adjustment required to achieve proper white balance for the image.

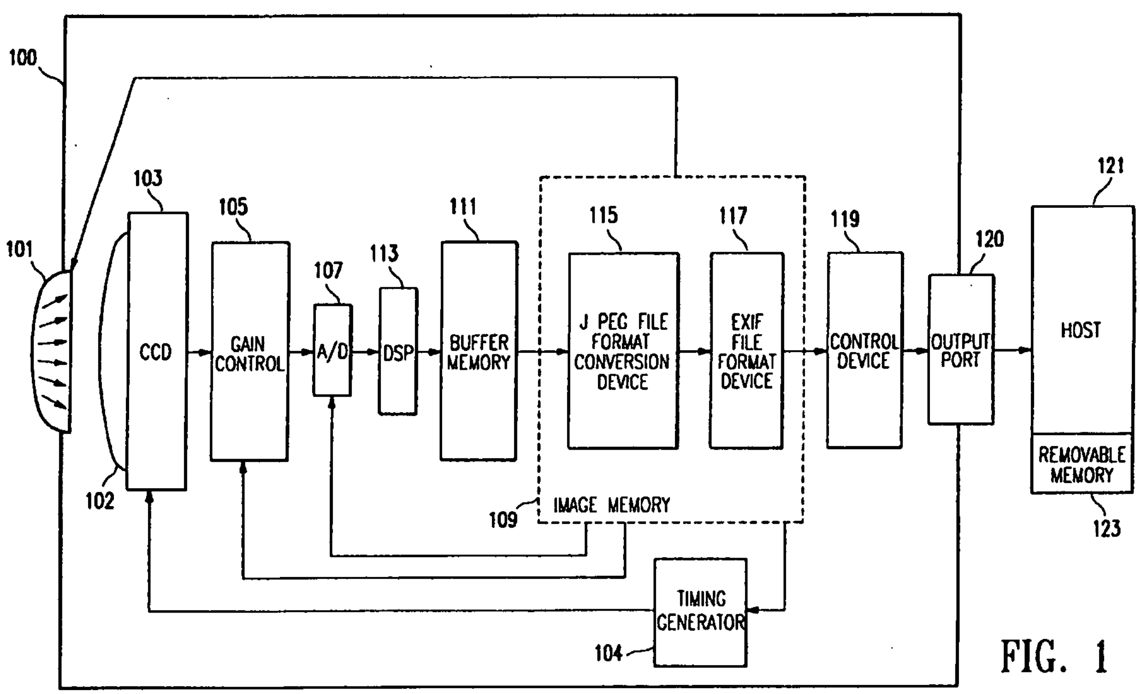

FIG. 1

EP 0 862 336 A2

Printed by Jouve, 75001 PARIS (FR)

Description

BACKGROUND OF THE INVENTION

1. *Field of the invention*

This invention relates to digital cameras, and more particularly to a method and apparatus for performing color adjustment upon images taken with a digital camera.

2. *Description of related Art*

Digital still cameras are being developed today to allow an image to be captured, digitized, stored, and reproduced using conventional printers coupled to a conventional personal computer. In most cases, an array ofcharge-coupled-device (CCD) detectors are used to capture the image. Each detector of the CCD array is used to capture one portion of the image. When light is received by a CCD detector, an electrical charge representative of the intensity of the light to which the detector has been exposed is accumulated. This charge can be coupled to an A/D (analog to digital) converter. The AID convertor produces a digital value that represents the charge on each of the detectors, and thus the intensity of the light received by each detector.

If a color image is to be captured, then color filters are placed before each detector of the CCD array. Accordingly, a detector which is associated with a filter that passes essentially only red light will form a red detector. The color detectors are frequently arranged in groups. For example, in one well known arrangement, two green detectors. a blue detector. and a red detector form a two by two grouping. This grouping is repeated throughout the array of detectors. By taking the digital value associated with each detector. the color composition of the image is captured.

One problem that is encountered is that the amount of color detected by each detector may be altered due to the composition of the spectrum of light emitted by the particular light source which illuminates the image. For example, if an image is illuminated by a tungsten light source, then the image will be shifted toward the red spectrum, since tungsten light sources emit more red light than blue or green light. This shift will give the resulting photograph an undesirable reddish/orangish appearance.

In accordance with one method that has been used to process an image to adjust for differences in the nature of the light, variable gain amplifiers are provided in line with the red and blue signals. The amount of gain applied to the red and blue signals is adjusted to compensate for the type of light which illuminates the image. A manual control on the camera allows the user to select between tungsten mode and daylight mode. In tungsten mode, the gains of the amplifiers that are responsible for amplifying the output from the red and blue detectors are set to a first gain ratio to compensate for the blue shift. In daylight mode, a second gain ratio is used which causes the gain of the amplifiers responsible for amplifying the red and blue signals to be approximately equal to the amount of gain which is set for the green signals.

Selection of the particular gain ratio is also dependent upon the state of a relay. The relay overrides the manual control when a flash has been charged, since the use of a flash will alter the color composition of the image. That is, the gain ratio of the color signal amplifiers should be essentially the same when capturing an image using a flash device and when capturing an image during daylight. Therefore, when a flash device is charged to illuminate an image, the relay sets the mode of the variable gain amplifiers to the daylight setting, as is appropriate in the case in which a flash is to be used. Thus. by altering the gain of the amplifiers responsible for amplifying the outputs from the red and blue detectors, the color is properly balanced for the case in which an image is to be captured in tungsten lighting, daylight, or when a flash is used.

However, this system can improperly adjust the color of the image that is captured if the flash is charged, but not actually activated. Furthermore, the amount of color adjustment that is preformed is essentially fixed at one of two particular ratios (i.e., the gain of the amplifiers is set to one of two levels). Accordingly, if the amount of color adjustment that is required is other than that which would be desirable if the image were illuminated solely by tungsten or solely by natural sunlight, then the color of the image will be improperly adjusted. Still further, not every tungsten light source will have exactly the same color temperature (spectral composition of wavelengths).

A common way in which digital cameras have attempted to white balance an image requires that a preview image be taken. The preview image is used to determine the amount of adjustment that is required in order to white balance the image. There are several historical reasons why a preview image is used to determine the amount of adj ustment that is required to white balance an image that is taken some time later. For example, in the case in which the adjustment is made by adjusting the gain of the amplifiers to which the output from the CCD array is coupled, the white balance information must be known at the time the image is read from the CCD array.

However, the adjustment will be incorrect if the illumination of the image differs between the time the preview image is taken and the time the final image is taken. For example, if the preview image is taken without a flash, and the final image is taken with a flash, then the correction that is made to the final image based upon the characteristics of the preview image will be incorrect. A number of other situations can arise which would cause the illumination of the preview image to differ from the illumination of the final image. For example. the sun may become obscured by a cloud. a light may be turned

on or off. etc.

Accordingly, it would be desirable to provide a system wherein the color adjustment is determined in a way that accurately reflects the characteristics of the final image. Furthermore. it would be desirable to provide a system wherein the amount of color adjustment can be adjusted to compensate for several different conditions and combinations of light sources.

SUMMARY OF THE INVENTION

The present invention is a method and apparatus for performing color balance of an image taken with a digital camera using either an host computer that is external to the camera or in a device internal to the camera using the image data of the image to be white balance adjusted in order to determine the amount of adjustment required..

In accordance with the present invention, a digital image is captured by: first flushing, at a first point in time, any charge which has accumulated on a CCD light detector array; allowing light to strike the CCD detector after the detector has been flushed; and determining the amount of charge that has accumulated upon the detectors that comprise the array. Once the image has been captured, a determination must be made as to whether the image requires white balancing. White balancing is typically required if the light source that illuminates objects to be imaged has a "color temperature" that would cause the image to be tinted or biased in favor of, or away from, one color. For example, a tungsten light source will typically be biased in favor red. Therefore, in order for the image to be properly white balanced, the red component of each pixel must be adjusted with respect to the blue and green components of each pixel.

In accordance with the present invention, the amount of the adjustment which is to be made is determined by analysis of the image data to be adjusted (i. e., the "picture image"). In accordance with one embodiment of the present invention, image pixels within the picture image are mapped into a two dimensional space, the two dimensions of this space being red/blue and green/blue. Image pixels that make up a reference image that was illuminated by a reference light source are then plotted in the two dimensional space. Each of the points at the periphery of the picture image are mapped into points at the periphery of the reference image by a transform. The transforms that are used to map the points in the picture image to the points in the reference image are then plotted in a transform space. A shape is defined in the transform space by the set of transforms associated with each of the points on the periphery of the picture image. Accordingly, a set of such shapes in the transform space will be defined for the picture image. The intersection of these shapes is then used to determine source of light that illuminates the picture image and the adjustment factors required to properly white balance the picture image.

It will be clear that since the image data to be adjusted is used to determine the amount of the adjustment that is required, the adjustment will be more precise than would be the case if a preview image is taken to determine how to adjust the picture image.

In accordance with one embodiment of the present invention, the analysis and adjustment ofthe image data is performed in the camera. However, in an alternative embodiment of the present invention, the adjustment is performed outside the camera by a host device, such as a personal computer or printer.

BRIEF DESCRIPTION OF THE DRAWING

The objects, advantages, and features of this invention will become readily apparent in view of the following description, when read in conjunction with the accompanying drawing, in which:

Fig. 1 is a block diagram of a digital camera in accordance with the present invention.

Like reference numbers and designations in the various drawings refer to like elements.

DETAILED DESCRIPTION OF THE INVENTION

Throughout this description, the preferred embodiment and examples shown should be considered as exemplars, rather than limitations on the present invention.

The present invention is a method and apparatus for performing automatic white balance on an image captured by a digital camera based upon characteristics of a light source as determined from an analysis of the image data.

Figure 1 is a block diagram of one embodiment of a digital camera 100 in accordance with the present invention. The digital camera 100 includes: an optical lens 101; an array of charge-coupled-device (CCD) detectors 103, including an array of color filters, each filter associated with a detector; a gain control circuit 105; an A/D (analog to digital) convertor 107; a control device 109 (such as a microprocessor), preferably including a JPEG file format conversion device 115 and an EXIF file format device 117; a buffer memory 111; an image processing device 113, such as a DSP (digital signal processor); an image memory device 119; and an output port 120.

Light enters the digital camera 100 through the lens 101 and is focused on the array of CCD detectors 103. As is well known in the art, the color filters 102 associated with each detector within the CCD array 103 cause the detectors to be sensitive to one particular color. In accordance with one embodiment of the present invention. the CCD detectors are configured in a repeating pattern of two by two groups in which the top right detector is sensitive to red light, the top left detector is sensitive to blue green light, the bottom right detector is sensitive to green light, and the bottom left detector is sensitive to blue light. It should be understood that the array

of detectors may be fabricated such that the particular detectors are sensitive to other colors and are arranged in other configurations.

Each detector accumulates a charge that is representative of the amount of light in one CCD pixel. A timing generator 104 is coupled to the CCD detector array 103. The timing generator 104 controls the reading of the CCD detector array 103 in essentially conventional fashion. The timing generator 104 causes the charge accumulated by each detector to be serially applied to the input of the gain control device 105. The control device 109 is coupled to the timing generator and controls the operation of the timing generator 104 in essentially conventional fashion.

The timing generator 104 is capable of flushing the CCD array 103 to essentially discharge any charge previously accumulated the detectors within the array. Once the CCD array 103 has been flushed, the light that passes through the lens and the color filters causes charge to accumulate on each of the detectors within the CCD array 103 in an amount that is proportional to the amount of light that strikes each detector. The charge that accumulates on each detector within the CCD array 103 results in a voltage that is coupled to the gain control circuit 105. The gain control circuit 105 includes an automatic gain control circuit and circuitry to implement a correlated double sampling process. The correlated double sampling piocess is a conventional process which accounts for overshoot and undershoot in the output from the CCD detectors as the CCD array is read.

The control device 109 is coupled to the gain control device and controls the automatic gain control circuit. The output from the gain control circuit 105 is coupled to the A/D converter 107. The AID converter 107 converts to digital values the voltages read from the CCD detectors and processed by the gain control circuit 105. The resulting digital values are preferably directly proportional to the amount of light detected by each detector.

The A/D converter 107 is coupled to the DSP 113. The DSP 113 processes the color information stored in the buffer memory 111 to provide a demosaic function. to perform automatic white balance, and to sharpen the image. The DSP 113 determines which values are coupled from the A/D converter 107 to the DSP 113 are associated with which detectors by the order in which the values are received from the A/D converter 107. The demosaic function and the automatic white balance functions are conventional functions. For example, in accordance with one embodiment of the present invention, the DSP 113 is a Part No. HD49811TFA commercially available from Hitachi and the automatic white balance function is provided in the HD49811TFA data sheet distributed by Hitachi. The output from the DSP 113 is a set of image pixels, each of which represent the color of a particular portion of the image that was captured by the CCD detector array 103. Accordingly, the complete set of image pixels comprise the image data. The image data is stored in a buffer memory 111. The buffer memory 111 is read by the control device 109.

In accordance with one embodiment of the present invention, the control device 109 includes a conventional dedicated integrated circuit which performs a JPEG file format conversion. Therefore, in accordance with one embodiment of the present invention, a combination of hardware and software executed within the control device 109 operate together to form a JPEG file format conversion device 115. However, in accordance with another embodiment of the present invention, the JPEG file format conversion device comprises only hardware. Alternatively, the JPEG file format conversion device 115 is a software routine performed within a programmable control device 109. In either case, file format conversion is performed in conventional fashion. In yet another embodiment of the present invention, no compression is performed. In still another embodiment, compression is performed in accordance with a standard other than JPEG.

The JPEG file format conversion process compresses the information output from the DSP 113 and stored in the buffer 111 in accordance with the well known JPEG data compression standard. The information which is in JPEG format is then embedded within a file which conforms to "Digital Still Camera Image File Format Standard" (Version 1.0. July 13. 1995) (commonly known as "EXIF"). defined by the JEIDA Electronic Still Camera Technical Committee. The file is embedded within the EXIF file by an EXIF file format device 117 within the control device 109. In accordance with one embodiment of the present invention, the EXIF file format device is a combination of software executed within the control device 109 and dedicated hardware.

However, in an alternative embodiment, the EXIF file format device 117 is a software routine performed within the control device 109. In yet another embodiment of the present invention, the EXIF file format device 117 comprises only dedicated hardware.

In the preferred embodiment of the present invention, the image information is compressed in accordance with the well known JPEG data compression technique and presented in YC_bC_r format with 4:2:2 subsampling. The EXIF file is then transferred to a host for further processing. However, it should be understood that in accordance with an alternative embodiment of the present invention, the output from the DSP 113 may be formatted in any manner which allows a host 121, such as a personal computer or printer, to read and interpret the information provided by the camera 100 to the host 121. In accordance with one embodiment of the present invention, the image data is not compressed.

In accordance with the present invention, the image data is analyzed to determine how to adjust the digital values in the image data to correct for differences in the characteristics of the light source used to illuminate the image. In accordance with one embodiment of the

present invention, the image data is analyzed to determine the amount of adjustment to be applied to the image data to properly white balance the image. The analysis involves mathematical manipulation of the image data which can be performed by a programmable device, such as a microprocessor or DSP either within or external to the camera (e.g., in the host). In accordance with one embodiment of the present invention, the image data is analyzed with respect to a reference image. The reference image preferably has an essentially full spectrum of visible wavelengths and is illuminated by a reference light source. The image data for the reference image is mapped into a two dimensional space in which the horizontal axis is red divided by blue and the vertical axis is green divided by blue. This mapping reduces the three dimensional (rgb) points to chromaticity defined by two values (i.e., the red/blue value and the green/blue value). Accordingly, a gamut of points can be plotted in this two dimensional space. each point representing the color of one pixel in the reference image. A set of points which, when connected from one point to the next, define the outer most boundary of this reference gamut are identified. These peripheral points are then saved.

Once the peripheral points of the reference image have been established, a picture image can be analyzed with respect to the reference image by first mapping the picture image into the two-dimensional space such that each pixel defines a point in the two-dimensional space. Then peripheral points for the picture image are determined. Each one of these points are than mapped to one of the peripheral points of the reference image. The transform that is used to map the peripheral point of the picture image to the peripheral point of the reference image is then defined by two values. The first value is the quotient of the red/blue values, and the second value is the quotient of the green/blue values. Each set of transforms associated with one point of the picture image and mapped to each point in the reference image will define a shape. Therefore, a set of shapes will be defined by mapping each of the points in the picture image to each of the points in the reference image. The intersection of these shapes defines a new shape. This new shape can then be analyzed to determine the light source which most likely was used to illuminate the scene.

It should be understood that in an alternative embodiment of the present invention, the image data may be analyzed by any other methods for determining the adjustment required to color balance the image.

In another embodiment of the present invention, the device for analyzing the image data is provided within the camera. For example, in one embodiment of the present invention, the DSP 113 performs the analysis of the image data. As a result of the analysis of the image data. the color of the image pixels that make-up the image are adjusted to achieve proper white balance. It should be understood that the image data may not be compressed. or the compression may be applied after either analysis of the image data or after the adjustments to the color balance are made.

Summary

A number of embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Furthermore, the components of the digital camera are described as one example of devices which perform particular functions within a digital camera. Accordingly, the functions which are described as being performed within the digital camera may be performed by any device that is capable of performing the particular functions. For example, the control device 109 may be a microprocessor, an application specific integrated circuit, a discrete circuit, a state machine, or any other circuit or component that is capable of performing the functions that are described above. Accordingly, it is to be understood that the invention is not to be limited by the specific illustrated embodiments, but only by the scope of the appended claims.

Claims

1. A digital camera (100), comprising:

an image sensing arrangement (101, 102, 103, 104, 105, 107) for capturing an image and its color composition resulting from a source of image illuminating light;

an image storage arrangement (111, 113, 115, 117) responsive to said image sensing arrangement for storing non-color-corrected data indicative of said captured image; and

a color compensation arrangement (109, 119, 120, 121, 123) for analyzing the stored non-color-corrected data to define a set of transformation values that enable the non-color-corrected data to be automatically color balanced without using a pre-exposure scene sampling.

2. A digital camera (100) according to claim 1, wherein said image sensing arrangement (101, 102, 103, 104, 105, 107) includes:

a sensor array (103) for converting light into electrical energy;

an array of color filters (102) for causing said sensor array (103) to be sensitive to certain specific color spectrums; and

an optical lens (101) for directing light from an

illuminated image onto said array of color filters (102) to facilitate capturing the color compensation of said image when illuminated by said source of light.

3. A digital camera (100) according to claim 2, wherein said sensor array (103) is an array of charge coupled devices.

4. A digital camera (100) according to claims 2 or 3, wherein said sensing arrangement further includes:

a timing generator (104) coupled to said sensor array (103) for facilitating the sequential reading of discrete pixel data values;

a gain control circuit (105) coupled to said sensor array (103) for correcting overshoot and undershoot signal anomalies in processing the captured image from said sensor array (103) into the discrete pixel data values; and

an analog to digital converter (107) for converting each discrete pixel data value into a discrete digital value indicative of one pixel of non-color-corrected data.

5. A digital camera (100) according to any one of the preceding claims, wherein said color compensation arrangement (109, 119, 120, 121, 123) includes:

a processing circuit (109, 119) for analyzing each discrete digital value indicative of a pixel of non-color-corrected data has a sufficient color shift due to the spectral characteristics of said source of light to require white balance adjustment;

a control device (120, 121, 123) responsive to said processing circuit (119) for adjusting individual ones of the pixels of non-color-corrected data with sufficient color shift to require white balance correction.

6. A digital camera (100) according to any one of the preceding claims, wherein said color compensation arrangement (109, 119, 120, 121, 123) includes:

a host arrangement (120, 121, 123) having:

an analysis circuit for analyzing the non-color-corrected data to determine whether it needs color balancing due to the spectral characteristics of said source of light; and

a control device responsive to the analysis circuit for adjusting the non-color-corrected data when a determination is made that color balancing is required to compensate for color shifting in the captured image resulting from the spectral characteristics of said source of light.

7. A digital camera (100) according to any one of the preceding claims, wherein said color compensation arrangement (109, 119, 120, 121, 123) includes:

a digital processing apparatus (119) for executing a control program; and

an image memory arrangement (109) for formatting and converting the non-color-corrected data.

8. A digital camera (100) according to claim 7, wherein said control program causes said digital processing apparatus to automatically adjust the color balance of said captured image, said digital processing apparatus including means responsive to said control program to cause the non-color-corrected data to be analyzed with respect to a reference image to determine whether individual ones of the pixel data values need to be adjusted to achieve a proper white balance relative to said source of light causing the illumination of the captured image.

9. A digital camera (100) according to claim 8, wherein digital processing apparatus includes:

two-dimensional space means responsive to said control program for mapping image data for said reference image into two dimensional color space having a horizontal axis reference indicative of the red color spectrum divided by the blue color spectrum and a vertical axis reference indicative of the green color spectrum divided by the blue color spectrum;

wherein said reference image comprises a set of digital pixel values of an object illuminated by a reference light source that includes substantially the full spectrum of visible wavelengths of light; and

wherein said two-dimensional space means transforms three-dimensional chromaticity space points into two-dimensional color space points of red divided by blue digital values and green divided by blue digital values, each point in the two-dimensional color space being indicative of the color of one pixel in said reference image; and

wherein the outer most boundary values of the two-dimensional color space defining the reference image define a reference gamut, said reference gamut being stored to facilitate color

balancing image transformation purposes; and

wherein said two-dimensional space means is further responsive to said control program for mapping the non-color-corrected data indicative of the captured image into the two-dimensional color space to define each pixel value in the captured image; and

wherein the outer most boundary values of the two-dimensional color space defining the captured image define a non-color-corrected gamut referenced to said reference gamut; and

transformation means responsive to said control program for establishing a set of transformation values for each pixel of the captured image, each one of set of transformation values including two discrete values, one value being the quotient value of the red spectrum component of the pixel divided by blue spectrum component of the pixel and the other value being the quotient value of the green spectrum component of the pixel divided by the blue spectrum component of the pixel;

wherein each set of transformations associated with an individual pixel in the captured image is mapped to an associated pixel in the captured image to define a shape so that a set of intersecting shapes are defined where the intersection of the shapes define a new set of shapes that help facilitate determining the light source most likely utilized in illuminating a scene indicative of the captured image without using pre-exposure scene sampling.

10. A system (100) for automatic white balance detection and correction, comprising:

memory mean (101, 102, 103, 104, 105, 107, 111, 115, 117, 119, 120, 123) for capturing and storing non-color-corrected data indicative of a captured image illuminated by a source of light, said captured image being defined by a plurality of individual pixels;

determining means (113, 119) coupled to said memory means for analyzing the non-color-corrected data to determine the white balance of each individual pixel in the captured image relative to a reference light source without using a pre-exposure scene sample; and

color balance means (121) responsive to said determining means for adjusting the white balance of each individual pixel in the captured image so that white balance of each pixel is adjusted relative to said reference light source.

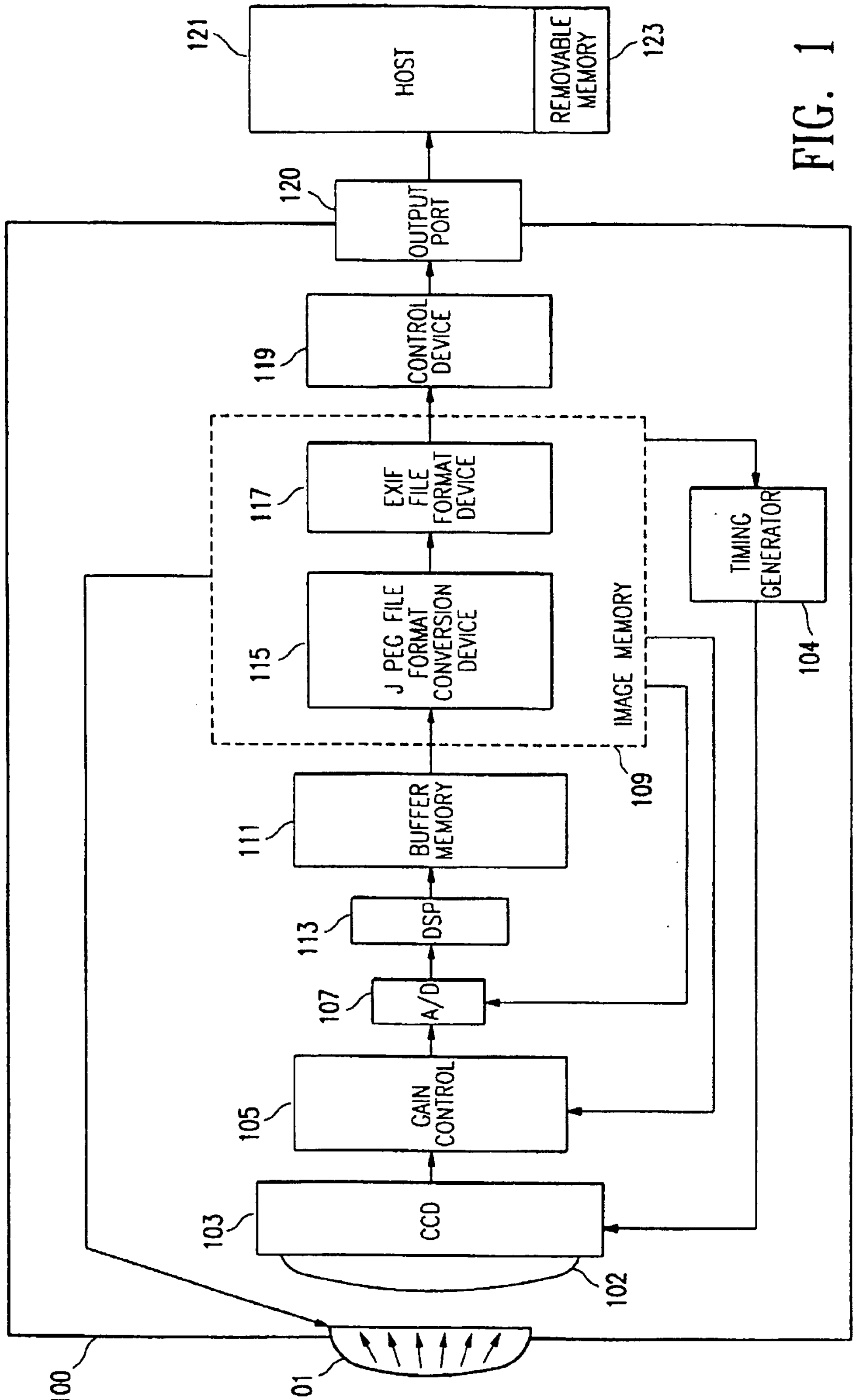
HOST
121
REMOVABLE MEMORY
123
OUTPUT PORT
120
CONTROL DEVICE
119
EXIF FILE FORMAT DEVICE
117
J PEG FILE FORMAT CONVERSION DEVICE
115
IMAGE MEMORY
109
TIMING GENERATOR
104
BUFFER MEMORY
111
DSP
113
A/D
107
GAIN CONTROL
105
CCD
103
102
101
100

FIG. 1